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Computer-Aided Dynamic Navigation in Endodontics: A Review.

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Abstract:
The innovative concept of Dynamic Navigation has been reported as an effective approach to obtain safe and reliable outcomes in Minimally Invasive Endodontic procedures. The aim of this review is to: (i) Present the most relevant literature highlighting the clinical applications, accuracy, relative advantages and also limitations of Dynamic Navigation, with a focus on Guided Endodontic Access Cavity preparation and Guided Endodontic Surgery; (ii) Make recommendations for the use of Dynamic Navigation in Endodontics based on current evidence; (iii) Highlight the areas in which more research is required.

Keywords: *Computer-assisted treatment, Dynamic Navigation System, Image-guided treatment, Minimally Invasive Endodontics, Real-time tracking*

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I. Introduction

In everyday clinical practice, any strategy or guidance that allows for minimally invasive endodontic procedures by preserving structural integrity and reducing the risk of iatrogenic injury while satisfying all minimally invasive endodontic criteria is to be welcomed.

For some time now, the concept of using guidance was an area of concern in implant surgery. Proper placement is essential to place implants at the correct angulation and depth. The advent of CBCT has changed the treatment preparation to assess the optimal location of an implant before surgery when taking account of significant anatomical surrounding structures. Thus, strategies for improving the precision of implant surgery have been developed using guidelines based on CBCT results.[1]

II. Types of Guidance

There are essentially two guides: Static and Dynamic.[2]

Static guidance:

Static guidance refers to the use of a fixed surgical stent based on a preoperative CBCT scan, which is produced with computer assisted design/computer assisted production (CAD / CAM). Static surgical guides can be supported by tooth, mucosa or bone.[3] A disadvantage of the Static surgical guides is that the expected angulation, size, depth or implant type cannot be adjusted quickly as it is made.[4] Other issues include costs of processing and time necessary for planning and manufacturing of Static guides. Static guides may not be available for patients with restricted opening of their mouths, or for patients with poorer access in the second molar regions.[5]

Dynamic guidance:

Dynamic guidance was first mentioned in 1998 at a medical imaging symposium. It is based on computer-aided surgical navigation technology and analogous to global positioning systems or satellite navigation. It has been used in a number of areas in medicine, such as craniomaxillofacial surgery.[6] In Dynamically guided implant surgery, the position of the virtual implant, correlated to reference points, is planned using computer software and the imported preoperative CBCT data. A system of motion-tracking optical cameras and pictures of the position of the virtually planned implant then provides real- time dynamic plus visual feedback to intraoperatively guide surgical implant instruments. Therefore, information that has been planned on the scan is transferred to the real-life clinical situation and the exact position of the handpiece can be tracked.[5]

To date, there are insufficient data assessing the use of Dynamic Navigation in Endodontics. Therefore, the aim of this review is to present the most relevant literature highlighting the clinical applications, accuracy, relative advantages and also limitations of Dynamic Navigation, focusing specifically on Guided Endodontic Access Cavity preparation and Guided Endodontic Surgery.

What makes Dynamic Guidance for Endodontic procedures superior to Static Traditional Drill Guidance?

The most profound advantage is that the just-in-time nature of the Dynamic guidance treatment planning, allowing access to be cut during a difficult emergency case within 10 minutes of the CBCT capture. Even with Static guides fabricated just in time with 3-D printers or milling machines, the 4-hour step of truly making the guide is obviated with Dynamically Guided Access (DGA). The benefit of a Dynamic guide over a Static guide is that the operator cannot deviate from the planned path which facilitates treatment for less experienced operators. Similarly, the immediacy of this guidance system allows adjustments to be made in programmed drill paths literally during the process, such as changing a drill path when faced with unforeseen clinical difficulties. The advantages of the Dynamic Navigation System over a static guide include a one-appointment procedure (scan, plan, and treat), verifiable guidance with system checks and drill visualization during the procedure, quick and easy planning, no need for an intraoral scan, and it can be used with limited interocclusal space because a template is not needed. Also, DGA is completed with an equivalent lengths of access burs that might normally be used, unlike static drill guides that need drills 10 mm longer than usual, which makes static guidance an impossibility in posterior teeth. Finally, guide rings can't be overlapped in static drill guides, requiring a separate guide for every canal, making it cost prohibitive.

III. Dynamic Guidance Systems

Dynamic Guidance Systems for implant placement that have been developed include RoboDent (RoboDent), X-Guide (X-Nav Technologies), Image Guided Implantology (Image Navigation), and Navident (ClaroNav, Toronto, Ontario, Canada).

Navident (ClaroNav, Toronto, Ontario, Canada) is a compact, easy-to-use device that allows dental surgeons to plan implant placement on a virtual patient and then install the fixture with greater precision and real-time 3-dimensional control using a computer-assisted technique (Fig. 1). These features can aid in lowering the risk of unintended iatrogenic damage to nearby anatomic structures and allowing for minimally invasive or flapless surgery, resulting in less patient postoperative pain and improved healing.[7,8] An in vitro study showed that the Navident Dynamic Navigation system allowed more accurate implant placement in comparison with the conventional freehand method, regardless of the surgeon's experience. The system, however, seemed to offer more advantages to novice professionals because it allows them to reduce their deviations significantly and achieve results similar to those of experienced clinicians.[9]

Fig 1: The Navident (ClaroNav) mobile unit with an overhead light, stereoscopic motion-tracking cameras and a mounted laptop computer with uploaded implant planning software.

3D Dynamic Navigation with X-guide (X-Nav Technologies, Lansdale, PA, USA):
The principal features of this system are the following:
1) An attachment for the handpiece
2) A jaw attachment for the patient (X-clip)
3) A system cart with stereo cameras (tracker), a computer, and a monitor with robust X-guide software.
Most CBCT 3D systems are compliant with this system. With the X-clip fiducial in place, a CBCT scan should be performed, after which the dentist may be able to import the scan into the database and schedule the implant planning using the software. During the treatment, the sensor attachment must be attached to the handpiece, and the jaw attachment must be attached to the patient's X-clip.

IV. Advantages of Dynamic Navigation Systems

- Reduces errors and is preferable to manual implant positioning (freehand).[4,10-12]
- They are similar or superior to other computerized procedures, including Static guides and are more accurate.[12,13]
- Entry error of around 0.4 mm and an angular deviation error of around 4° was recorded for the Dynamic Navigation implant systems.
- The Dynamic Navigation's high precision has also been identified as minimizing the possible risk of injury to vital anatomies,[14] including nerves and neighboring teeth, and increasing intraoperative safety, leading to significant improvements in the efficiency of implant surgery.[15]
- The flexibility given to the user is a big advantage of the Dynamic Navigation technology.

Adjustments to the surgical schedule can be made at all times depending on the clinical condition.[5]

- The seamless automated dynamic navigation workflow enables it to be used every implant patient, as opposed to rigid guides.[4]
- Preparing the surgery or other potential dental operations virtually ahead of time allows for a well-prepared operation.
- Patient chair time decreased.
- Enhanced productivity of dentists.
- The results are predictable and reproducible.

V. Disadvantages of Dynamic Navigation Systems

- The CBCT scan resolution can influence virtual planning of the preparation of an endodontic access or an osteotomy.
- Flaws in the fabrication process of fiducial integrated stents will lead to inaccurate image acquisition.
- Expensive for equipment procurement, upgrades, and device repairs.
- Multiple recalibrations are needed during a single operation.
- Clinician's inability to operate through the dental operating microscope—requirement to look at the monitor when doing the guided procedure.
- Heavy and cumbersome sensors on both the handpiece and the patient.
- Increased care costs for patients.
- Need for a wider field of view CBCT.[16]

Dynamic Navigation proffers new prospects for Computer Guided Endodontic protocols. This technique has the potential to be applied in Endodontics for access cavity preparation especially in cases with severe canal calcification. In addition, it can be utilized in cases with dental developmental malformations such as Dens Invaginatus/ Evaginatus, fiber post removal, even for performing a conservative osteotomy and root end resection in endodontic microsurgery. It can be used with an educational interest for finding of root canals.

VI. Dynamic Navigation System (Innovation Navigation)

Real-time computer guidance technology with an import CBCT data collection is facilitated by Dynamic Navigation. The GPS and satellite navigation are similar in this case. The Canadian company ClaroNav has created an advanced Computer-Guided Technology, Trace and Place (TaP). TaP avoids the need for a fiducial stent, with the resultant increase in the accuracy of dento-osseous penetration. A Jaw - Tracker, optically attached to the patient's jaw and an optical tracking tag, which is the optical tracking tag connected to a treatment specific instrument, are tracked using an optical tracking system (Fig. 2). The tip is superimposed on a CBCT scan of the patient's jaw that has been traced. TaP technology's increased precision improves the ease of care for restricted access cavity planning and reduces the size of cortical window osteotomies (high-speed; Piezotome, ACTEON). Dynamic Navigation applications can also detect ultrasonic tips used for root end retro-preparation.

Fig. 2: An optical tracking sensor tracks the Jaw-Tracker, Tracer-Tracker, Drill-Tracker and instrument

TaP workflow planning and trace registration
Prior to the appointment:

Importing the patient's CBCT data collection (as a DICOM file) into the Dynamic Navigation preparation program to reveal the dentition is the first step in the TaP workflow. The streaming video, panoramic view, target view, depth indicator, and buccolingual and mesiodistal segment views are all shown on the projector (Fig. 3). The access point of entry, axis orientation/angulation, and access cavity depth are all anticipated. The Piezotome pathway for microsurgical procedures is dependent on the dimensions of the osseous anatomy covering the root apex (Figs. 4a–c). If the CBCT scan is compatible with the present dentate state, the preparation stage can be completed at any time prior to the operation. Three to six trace starting points (landmarks) are selected and labelled on visible and accessible teeth as a preliminary step before the trace entry.

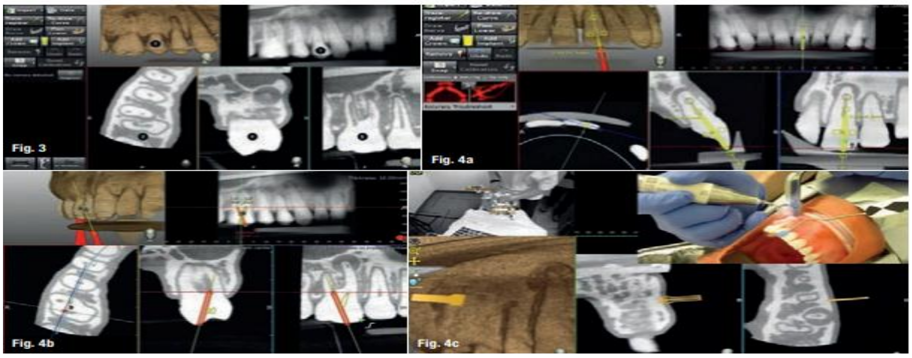

Fig. 3: The screen is divided into five sections: (1) panoramic view, (2) 3D reconstruction, (3) axial view, (4) buccolingual section, and (5) mesiodistal section. Fig. 4a: The virtual drill's intended axis angulation and orientation are precise in targeting calcified canals. Fig. 4b: An off-angle positioning is reflected by the red virtual pathway. Fig. 4c: Piezotome preparation.

A 2D cross-sectional view occurs while the virtual mouse is poised over the 3D model. The Red Cross hair sticks to the landmark, the center of which is visible on the floor (Fig. 5). If the program assumes that the landmark is in the wrong place, it alerts the clinician.

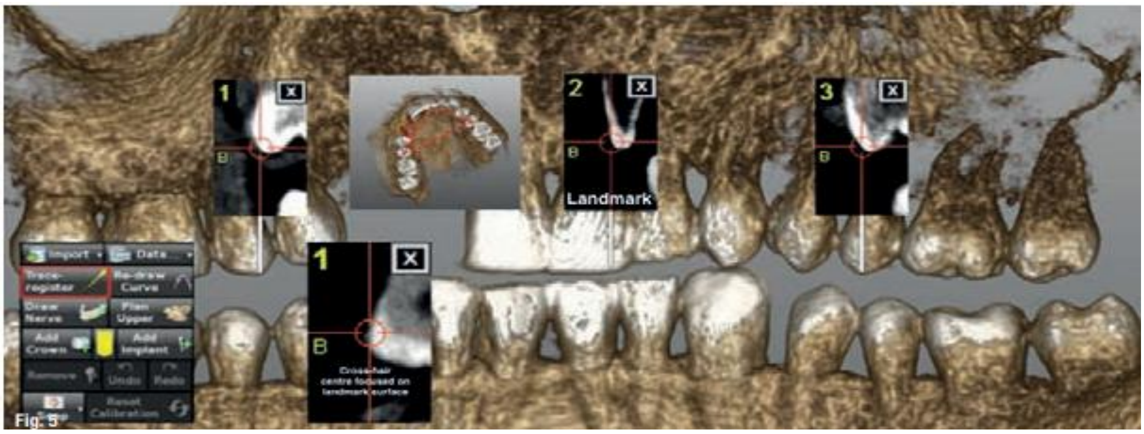

Fig. 5: The three landmarks selected are not collinear, and the thin red cross-hair that appears is centered on the landmark's surface.

Trace registration:

The Jaw-Tracker (mandible or maxilla) or Head-Tracker (maxilla) is secured to the jaw that will be handled (Fig. 6). In contrast to a Jaw-Tracker attached to a fiducial stent, which is more positionally limited, the Jaw-Tracker can be positioned at a distance from the rubber dam. The optical tracking sensor detects the Tracer-Tag/Tracer-Tool as it is brushed along the landmarks on the facial, lingual, and occlusal surfaces in a manner similar to applying etching or bonding solutions until the three landmarks have been determined. As a percentage, the software displays the number of point's contacted (Fig. 7).

Fig. 6: (1) The Jaw-Tracker has been mounted. (2) The system displays the percentage sampled up to 100 % during tracing.

Fig. 7: The Tracer-Tag and Tracer-Tool have been fitted, and the Tracer-Tool has been calibrated. As a percentage, the system displays the number of points contacted.

Calibration of the drill:

The Drill-Tag is attached to the handpiece, and the drill axis and drill tip have been calibrated. The optical monitoring sensor continuously tracks the Drill-Tag, and the software displays the drill or Piezotome location. If the Drill-Tag or Jaw-Tracker is not visible to the camera, the software will issue an alert (Figs. 8a & b).

Fig. 8a: The drill axis and the instrument tip have been calibrated. Fig. 8b: The Drill-Tag (optical tracking tag).

Dento-Osseous real-time navigation:

As the device recognizes the calibrated instrument as it reaches the patient's jaw, the navigation screen appears. The target view tests the distance of the entry point between the tip of the instrument and the central axis of it, the glide path or osteotomy. The center of the static, white targets reflect the central axis duration of the intended operation, and the tip of the drill is shown by the mobile black cross, accompanying the rotation of the drill tip. The real-time orientation of the drill is seen like a cone in the handpiece head (Figs. 9a & b).

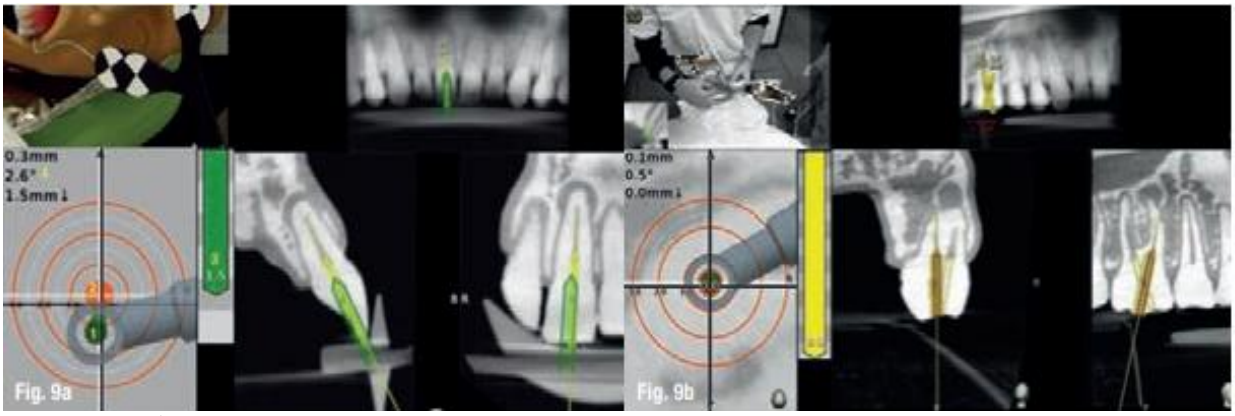

Fig. 9a: Calcified central incisor: (1) the drill is green; (2) the glide path or osteotomy's central axis; (3) the depth indicator; (4) the angle between the drill and the intended osteotomy's central axis. The depth symbol turns yellow as the drill and the central axis collide. Fig. 9b: The proposed canal position for the maxillary molar is on target (yellow: 0 mm).

The moving cross and cone are monitored during the drilling process. When the instrument tip is within 0.5mm of the intended glide path or osteotomy and has an angulation of less than 3°, the cone will turn green. The depth indicator turns yellow when the drill tip is 1mm away from the expected depth landmark's apical or horizontal extent.

VII. Dynamic Navigation Procedure for Endodontic Access Cavities

The removal of tooth structure required to prepare the access cavity for non-surgical root canal treatment will weaken the tooth by up to 63%.[17] The concepts of conservative and ultraconservative “ninja” endodontic cavity preparations have recently emerged.[18,19] However, in some circumstances, such as teeth with pulp canal calcification or dental developmental malformations, such as Dens Invaginatus/Evaginatus, where precise and conservative access cavities are needed to localize individual root canals, these new methods for freehand access cavity preparation are difficult to accomplish. In these situations, the use of splint guides based on cone-beam computed tomography (CBCT) data may reduce the risk of iatrogenic complications and preserve the coronal structure of the tooth.[20]

Dianat et al.[16] examined the performance (accuracy and efficiency) of a Dynamic Navigation System (DNS) to prepare access cavities in calcified human teeth and compare the results with the Free Hand (FH) technique. The results showed that the DNS system outperformed the standard FH CBCT approximated approach. As compared to the FH process, the DNS system had lower angular and linear differences, as well as a smaller reduction in dentinal thickness.

Studies show that perforation during access preparation can be a catastrophic mishap with negative impacts on the long-term tooth prognosis.[21,22] The DNS system was able to find root canals in 96.6 percent of teeth without perforation in a study performed by Dianat et al[16]. The FH approach showed 5 perforations and a slightly higher rate of mishaps (perforations and gouging). This is a significant discovery with important clinical implications. The DNS technique has shown the ability to preserve calcified teeth with endodontic disease that would normally be removed.

For both the patient and the clinician, the time taken to complete root canal therapy is a vital feature of endodontic treatment. Fewer visits, less local anesthesia, and shorter treatment times result in less emotional and physical fatigue for the patient and a healthier treatment environment for the practitioner. Shortening the treatment time, however, must not jeopardize the result. Dianat et al[16] demonstrated that the DNS system reduced access preparation time to an average of 4 minutes (maximum of 7 minutes) with no errors. In the FH group, the average time for finding canals was 7 minutes, with a range of up to 19 minutes. In a clinical setting, this period might be longer because of case complexity or the clinician’s anxiety of iatrogenic errors. In contrast to the FH group, this study found that the clinician's level of expertise had little bearing on the time it took to find calcified canals in the DNS group.

When compared to the FH technique, the DNS was more effective and successful at detecting canals in calcified human teeth. This innovative system resulted in a major reduction in tooth structure removal and a shorter procedure duration.[16]

Zubizaretta-Macho et al[23] compared the accuracy of the Navident DNS system (Claronav, ON, Canada) with static guides and an FH method in teeth without calcification. The DNS group had lower angular and horizontal deviations than the static and FH methods, indicating that it was more precise.

Jain et al[24] conducted an uncontrolled study on the precision of the Navident DNS using high-speed drills for locating simulated calcified canals in a 3-dimensional–printed tooth model. The findings showed a higher linear deviation than the DNS group in the study by Dianat et al.[16] A virtual tooth versus a natural tooth, the use of high-speed versus slow-speed drills, and the use of various DNS machines and data measurement techniques are among the variations between the studies.

Static guidance requires many stents to provide access to individual canals in multi-rooted teeth;[25,26] this is not the case with dynamic guidance. However, considering the location of the guiding mechanism and the need to angle the handpiece, the attached drill tag was difficult to recognize when it was out of the optical tracking field with three molar teeth. The redesign of the black and white drill tag will quickly fix this issue. Instead of one that is universal, specific tags for each tooth shape and position should be available.

The software can be used to design the access cavity preparation so that the apical end of the simulated implant is positioned in a straight line with the canal entry. However, there may be no patent canal before the middle or even the apical third of the teeth with severely calcified or obliterated root canal space. A buccal (facial) access cavity may be necessary to achieve straight access to the middle or apical third. It may not be suitable or desired for esthetic purposes. One potential alternative may be to prepare and do a two-stage drilling: an initial drill, to enter the coronal third and then changing direction to access the middle or apical third.

The walls of the access cavities prepared with the computer-aided Dynamic Navigation System are extremely narrow and parallel. While this may be in keeping with the concept of Minimally Invasive Endodontics it may hamper treatment procedures, including the efficacy of root canal instrumentation.[23]

VIII. Dynamic Navigation System in Endodontic Microsurgery

It has been shown that the size of the osteotomy and the speed of radiographic healing are directly related; a smaller osteotomy results in faster healing.[27] The Dynamic Navigation System uses overhead tracking cameras to relate the direction of the patient's jaw to that of the clinician's bur. It required the operator to precisely direct the bur in three dimensions (and easily verify it in various CBCT planes), lowering the probability of iatrogenic errors.[28] This is critical, particularly when lesions are close to noble structures, because operators can control many steps of the surgical process in real time and, eventually correct mistakes. [29]

The ability to differentiate the root tip from the underlying bone is a significant clinical issue during osteotomy.[28] Also for an experienced surgeon, finding the apex if the apical lesion has not fenestrated the buccal bone will be difficult. The sensitivity of the system enabled the operator to accurately identify the root tip in a recent case report by Gambarini et al.[30]; the osteotomy and root-end resection were completed easily and rapidly with a minimally invasive procedure without iatrogenic errors. This allowed for proper apical curettage and orthograde cavity control.

In this case,[30] DNS outperformed the traditional hand approach in endodontic surgery by a wide margin. It is difficult to accurately identify the root tip using traditional methods. Dynamic Navigation proved to be a reliable and simple method for achieving this aim while minimizing the size of the osteotomy. If the initial osteotomy is prepared by an inexperienced operator, the osteotomy is likely to be too large, negating one of microsurgery's key advantages.

Another significant advantage in microsurgery is the elimination or reduction of the bevel angle. The bur was precisely angled to cut the root end with a 10° bevel angle, and the cutting was visualized and controlled in real time on the display thanks to dynamic navigation. These findings may only be obtained by a professional specialist using the traditional hand method.

DNS has many benefits over static guides in endodontic surgical and nonsurgical treatments; due to the shorter surgical instrumentation, they can be used more effectively in posterior regions and in patients with limited openings. In contrast to Static Navigation, which uses cylinders inside guides, DNS do not need a complex drill system or surgical instruments. Since the clinician can visualize the surgery on a monitor in real time, any mistakes, if any, can be spotted instantly, and any changes, if necessary, can be implemented immediately. Such a possibility is extremely useful in surgical endodontics since different steps normally necessitate different instrument orientation, which a single static guide cannot provide. Because of the system's accuracy, fewer complications involving the inferior alveolar nerve or injury to adjacent tooth roots were found during endodontic surgery with dynamic navigation.[30]

IX. Errors

DNS errors are classified into three types: computer, patient/tooth, and operator. Any variation in tracking components may have an effect on accuracy. This include, but are not limited to, unstable X-clip seating, jaw attachment rocking, and eccentric drill rotation relative to the tracked handpiece handle. Patient movement during CBCT acquisition and radiopaque coronal restorations degrade image quality and, as a result, procedural precision. Another clinical condition that induces inaccuracy is tooth mobility. These factors are well monitored in an ex vivo setup, and may not be representative of a clinical scenario. Deviations assessed in clinical trials can be substantially higher than controlled ex vivo settings based on prior implant studies. To evaluate the precision, effectiveness, and predictability of endodontic access cavity preparation and microsurgery in patients, clinical trials using various systems are needed.[16]

X. Learning curve

When dealing with DNS, there is a learning curve for the operator. During viewing of the device, the user must maintain the right orientation and angle to the handpiece. In order to achieve skill, motor control, eye-hand coordination, manual dexterity, system awareness and continuing practice is required. In a clinical trial, the learning curve for dynamic navigation was significant as the level of expertise of a surgeon seems to increase the result.[31] The mean linear and angular deviations between the first and the final 50 implant operations have been significantly improved. Similarly, before attempting surgery on live patients, 20 trial attempts with the DNS were recommended.

Certain improvements to cumbersome attachments, updated versions of the software for an endodontic access module, the ability to connect various handpiece styles, and the use of virtual reality technology and head-mounted displays will also enable DNS use in all areas of endodontic practice.[16]

Further research is needed to determine the accuracy and clinical complications of endodontic access cavities, retreatment and microsurgeries performed using emerging technology.

XI. Conclusion

In dentistry, innovation occurs when there is a willingness to investigate and improve both diagnosis and treatment. The challenge is to marry the equipment and materials to new software applications in a seamless manner. Dynamic Navigation is a promising technique with a high degree of predictability and a low risk of iatrogenic damage. Treatment can be performed with minimal invasiveness, and chairside time can be reduced. However, this should be interpreted with caution because it is based on limited and low-quality evidence from case reports, observational studies, in vitro and ex vivo studies. Larger population trials with longer follow-ups and standardization with experimental studies of the same sample size, aim, objective, and standardized methods are essential.

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